Attorney Docket No. 9409-3 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Freese et al.
Serial No.: 10/661,917
Filed: September 11, 2003
For: METHODS FOR MASTERING MICROSTRUCTURES THROUGH A SUBSTRATE USING NEGATIVE PHOTORESIST

Confirmation No.: 8346
Examiner: Daborah Chacko Davis
Group Art Unit: 1795

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APPELLANTS' AMENDED BRIEF ON APPEAL UNDER 37 C.F.R. § 41.37

Sir:

This Amended Appeal Brief ("Brief") is filed pursuant to the "Second Notice of Appeal to the Board of Patent Appeals and Interferences", the "Second Pre-Appeal Brief Request for Review" electronically transmitted on November 8, 2007, and the "Notice of Panel Decision from Pre-Appeal Brief Review" mailed November 29, 2007, and is responsive to the "Notification of Non-Compliant Appeal Brief" mailed April 16, 2008.

In particular, pursuant to the Notification of Non-Compliant Appeal Brief of April 16, 2008, the "Grounds of Rejection to be Reviewed on Appeal" has been amended to include Claims 3-10 in Ground 1, and to add a new Ground 2 for Claims 11-13. Moreover, the "Arguments" section II has been amended to exclude Claims 11-13, and the arguments for each of Claims 1, 3, 4, 5, 6 and 8 have been numbered with separate section numbers "a."-"f." A new section "g." for dependent Claims 7, 9, 10 and 15-18 has been added, and a new section III for Claims 11-13 has been added. In the "Arguments" section II, the reference to U.S. Patent 7,092,165 has been replaced with reference to U.S. Patent Application Publication 2002/0030414, which was previously cited in an Information Disclosure Statement and was previously considered by the Examiner. The "Evidence Appendix" has been updated accordingly. Finally, the original "Summary of the Claimed Subject Matter" section has been replaced by the amended "Summary of the Claimed Subject Matter" section of "Appellants' Amended 'Summary Of Claimed Subject Matter' Section For Brief On Appeal Under 37 C.F.R.

§41.37" of January 31, 2008. The remaining sections of this Amended Appeal Brief are unchanged.

Real Party In Interest

The real party in interest is assignee Bright View Technologies, Inc., by assignment recorded on September 11, 2003 at Reel 014502, Frame 0317.

Related Appeals and Interferences

Appellants are aware of no appeals or interferences that would be affected by the present appeal.

Status of Claims

Claims 1, 3-13 and 15-18 remain pending in the present application as of the filing date of this Appeal Brief and are on appeal herein. Claims 1, 3-13 and 15-18 stand rejected in an Office Action mailed October 18, 2007 (hereinafter "Office Action"). Claims 2, 14 and 19-105 are canceled. The attached Appendix A presents the claims at issue as rejected in the Office Action. Appellants wish to note that the Office Action Summary of the Office Action indicates that Claims 21-30, 32-35, 38-42, 44 and 45 also remain pending. However, this is not the case, as these claims were canceled in an Amendment After Final Action dated May 22, 2007.

Status of Amendments

A final Office Action was issued in this application on May 3, 2007 and, in response, Claims 2, 14 and 19-105 were canceled in an Amendment After Final Action filed May 22, 2007. This Amendment was entered, but an Advisory Action of June 8, 2007 maintained the final rejection. Appellants then filed a Request for Pre-Appeal Brief Review on July 5, 2007, and a Notice of Panel Decision from Pre-Appeal Brief Review mailed August 6, 2007 reopened prosecution. Prosecution was reopened with the mailing of a non-final Office Action on October 18, 2007, wherein a new secondary reference was substituted for the original secondary reference, in a three reference rejection under 35 USC §103(a). In response, a second Request for Pre-Appeal Brief Review was filed on July 5, 2007. The Notice of Panel Decision from Pre-Appeal Brief

Review of November 29, 2007 indicated that the application should proceed to the Board of Patent Appeals and Interferences, which resulted in the present appeal. Thus, no amendments have been filed after the Amendment After Final Action of May 22, 2007. The attached Appendix presents the pending claims and corresponding status of each of the pending claims.

Summary of the Claimed Subject Matter

Some embodiments of the present invention according to independent Claim 1 provide a method of fabricating an array of microlenses (e.g., Figure 13A, microlenses **132**, specification Page 17, lines 4-9) by scanning a radiation beam (e.g., Figure 13A, radiation beam **820**, specification Page 17, lines 4-9) at varying amplitude through a substrate (e.g., Figure 13A, substrate **800**, specification Page 17, lines 4-9) that is transparent thereto into a negative photoresist layer (e.g., Figure 13A, negative photoresist layer **1310**, specification Page 17, lines 4-9) on the substrate to image the array of microlenses in the negative photoresist layer, as illustrated in Figure 13A.

Some embodiments of the present invention according to Claim 3 provide that the negative photoresist layer (e.g., Figure 17, negative photoresist layer **1310**, specification Page 19, lines 9-19) is thicker than the array of microlenses (e.g., Figure 17, microlenses **1732**, specification Page 19, lines 9-19) and wherein scanning comprises scanning a radiation beam (e.g., Figure 17, radiation beam **822**, specification Page 19, lines 9-19) at varying amplitude through a substrate (e.g., Figure 17, substrate **800**, specification Page 19, lines 9-19) that is transparent thereto into the negative photoresist layer on the substrate to image a buried array of microlenses in the negative photoresist layer, adjacent the substrate, as illustrated in Figure 17.

Other embodiments of the present invention according to Claim 4 provide that the microlenses (e.g., Figure 17, microlenses **1732**, specification Page 19, lines 9-19) include a base and a top that is narrower than the base, as illustrated in Figure 17, wherein scanning comprises scanning a radiation beam (e.g., Figure 17, radiation beam **822**, specification Page 19, lines 9-19) at varying amplitude through a substrate (e.g., Figure 17, substrate **800**, specification Page 19, lines 9-19) that is transparent thereto into a negative photoresist layer (e.g., Figure 17, negative photoresist layer **1310**, specification Page 19, lines 9-19) on the substrate to image the array of microlenses in

the negative photoresist layer with the bases adjacent the substrate and the tops remote from the substrate, as illustrated in Figure 17.

Other embodiments of the present invention according to Claim 5 provide that the negative photoresist layer (e.g., Figure 18, negative photoresist layer **1310**, specification Page 19, lines 20-28) is of variable thickness thereacross, as illustrated in Figure 18, wherein a minimum thickness of the negative photoresist layer is thicker than the microlenses (e.g., Figure 18, microlenses **1832**, specification Page 19, lines 20-28), wherein scanning comprises scanning a radiation beam (e.g., Figure 18, radiation beam **822**, specification Page 19, lines 20-28) at varying amplitude through a substrate (e.g., Figure 18, substrate **800**, specification Page 19, lines 20-28) that is transparent thereto into the negative photoresist layer on the substrate to image buried microlenses beneath the negative photoresist layer, adjacent the substrate, that are independent of the variable thickness of the negative photoresist layer, as illustrated in Figure 18.

Yet other embodiments of the present invention according to Claim 6 provide a method wherein the negative photoresist layer (e.g., Figure 19, negative photoresist layer **1310**, specification Page 19, line 29-Page 20, line 4) includes impurities (e.g., Figure 19, impurities **1910**, specification Page 19, line 29-Page 20, line 4) thereon, remote from a substrate (e.g., Figure 19, substrate **800**, specification Page 19, line 29-Page 20, line 4), wherein the negative photoresist layer is thicker than the microlenses (e.g., Figure 19, microlenses **1832**, specification Page 19, line 29-Page 20, line 4) and wherein scanning comprises scanning a radiation beam (e.g., Figure 19, radiation beam **822**, specification Page 19, line 29-Page 20, line 4) at varying amplitude through the substrate that is transparent thereto into the negative photoresist layer on the substrate to image buried microlenses in the negative photoresist layer, adjacent the substrate, that are not distorted by the impurities, as illustrated in Figure 19.

Yet other embodiments of the present invention according to Claim 8 provide that the negative photoresist layer is on a cylindrical platform (e.g., Figure 3, cylindrical platform **100**, specification Page 8, lines 19-28) and wherein scanning comprises rotating the cylindrical platform about an axis thereof (e.g., Figure 3, axis **102**, rotation arrow **104**, specification Page 8, lines 19-28) while simultaneously axially rastering the radiation beam (e.g., Figure 3, radiation beam **120**, axial rastering arrow **124**, specification Page 8, lines 19-28) at varying amplitude through the substrate that is on

the cylindrical platform across at least a portion of the negative photoresist layer to image the array of microlenses (e.g., Figure 3, microlenses **132**, specification Page 8, lines 19-28) in the negative photoresist layer.

Grounds of Rejection to be Reviewed on Appeal

1. Are each of pending Claims 1, 3-10 and 15-18 properly rejected under 35 USC §103(a) as being unpatentable over U.S. Patent No. 4,965,118 to Kodera et al. (hereinafter "Kodera") in view of U.S. Patent 6,292,255 to McCullough (hereinafter "McCullough") and U.S. Patent 6,410,213 to Raguin et al. (hereinafter "Raguin")?

2. Are each of pending Claims 11-13 properly rejected under 35 USC §103(a) as being unpatentable over Kordera in view of McCullough and Raguin and further in view of U.S. Patent 4,087,300 to Adler (hereinafter "Adler") and U.S. Patent No. 5,342,737 to Georger, Jr. et al. (hereinafter "Georger").

Argument

I. Introduction

All of the pending claims stand rejected as allegedly being obvious. To establish a *prima facie* case of obviousness, the prior art reference or references when combined must teach or suggest all the recitations of the claims, and there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. M.P.E.P. §2143. A patent composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art. *KSR Int'l Co. v. Teleflex Inc.,* 550 U. S. 1, 15 (2007). A corollary principle is that, when the prior art teaches away from combining certain known elements, discovery of a successful means of combining them is more likely to be unobvious. *Id.* at 12. If a technique has been used to improve one device, and a person of ordinary skill in the art would recognize that it would improve similar devices in the same way, using the technique is obvious unless its actual application is beyond his or her skill. *Id.* at 13. A Court must ask whether the improvement is more than the predictable use of prior art elements according to their established functions. *Id.* at 13. When it is necessary for a Court to look at interrelated teachings of multiple patents, the Court must determine

whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue. *Id.* at 14.

II. Claims 1, 3-10 and 15-18 Are Unobvious Over Kodera In View of McCullough And Further In View of Raguin

a. Independent Claim 1

Independent Claim 1 recites:

> 1. A method of fabricating an array of microlenses comprising:
>
> scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image the array of microlenses in the negative photoresist layer.

Thus, Independent Claim 1 recites a method of fabricating an array of microlenses comprising five interrelated recitations:

(1) scanning a radiation beam;

(2) at varying amplitude;

(3) through a substrate that is transparent thereto;

(4) into a negative photoresist layer on the substrate;

(5) to image the array of microlenses in the negative photoresist layer.

The present application, for example at Page 20, line 13-Page 21, line 12, describes various potential advantages in fabricating an array of microlenses using the five interrelated recitations. Appellants will now show that the combination of Kodera, McCullough and Raguin does not describe or suggest many of the recitations of independent Claim 1.

In particular, Kodera does not describe or suggest (1) scanning a radiation beam, (2) at varying amplitude, (3) into a negative photoresist layer on a substrate, (5) to form a latent image of the array of microlenses in the negative photoresist layer, as recited in Claim 1. Rather, as noted in Kodera Column 6, line 21-41:

> 1.2 Manufacturing method
> Most suitable material constituting respective components will be described while explaining a method of manufacturing the disk 100. First, as shown in FIG. 2, a resin mold 130, on which an uneven pattern 131 having an opposite relationship with respect to the uneven pattern corresponding to information to be recorded is formed, is

> prepared. A resin liquid 140 of the ultraviolet ray hardening type or the electron ray hardening type is painted on the resin mold 130. <u>From the side of the resin liquid 140, ultraviolet rays or electron rays 150 are irradiated, thus to harden and give form to the resin liquid 140.</u> The hardened resin layer serves as the resin layer 110. After this, the resin layer 110 is disconnected from the resin mold 130. <u>When needed, ultraviolet rays or electron rays are irradiated for the second time to complete hardening of the resin.</u> Since the resin thus hardened is subjected to three-dimensional bridging hardening, it exhibits a high heat resistance property and high solvent resistance property. (Emphasis added.)

Accordingly, in Kodera, there is no need to scan a radiation beam at a varying amplitude, because Kodera's flexible optical information recording medium is patterned by <u>molding</u> a resin onto a substrate having a pattern on it, as shown, for example, in Kodera Figures 1, 2, 4A and 4B. Rather than scanning, <u>flooding</u> of radiation is used to simply harden the molded resin, as noted in Kodera Column 8, lines 33-43. The flooding arrows **150** of Kodera Figure 2 and Figure 5 confirm that the scanning is not used and, in fact, there would be no need for scanning in Kodera for the reasons described above.

At the top of Page 4, the Office Action concedes:

> The difference between the claims and Kodera is that Kodera does not disclose that the radiation beam amplitude is varied (claims 10, 27, and 42).

However, Appellants have shown above that Kodera fails to disclose far more than varying the amplitude of radiation beam, in that the Kodera does not describe or suggest (1) scanning a radiation beam (2) at varying amplitude. Moreover, Kodera's radiation does not (5) form a latent image of the array of microlenses as recited in Claim 1. Rather, the radiation beam is merely used to harden the resin layer, but the array of microstructures is already formed mechanically by molding onto a patterned supporting layer.

In fact, Kodera does not even appear to use a photoresist whether positive or (4) negative, because Kodera's "resin liquid" does not appear to be capable of producing an image-wise pattern, and is not subjected to a development process. Rather, the resin liquid is simply hardened by irradiation of ultraviolet rays or electron rays, as described in the above-quoted passages of Kodera. Accordingly, Kodera would appear to be incapable of imaging an array of microlenses, even if a radiation beam was scanned at

varying amplitude. Kodera therefore does not describe or suggest recitations (1), (2), (4) or (5) of Claim 1.

In an unsuccessful attempt to supply the missing teachings, the Office Action cites McCullough. However, McCullough relates to a method and apparatus for varying the exposure dose during semiconductor integrated circuit manufacturing as a function of distance in a scan direction, to compensate for the signature of the photolithographic device and thereby reduce line width variation in the scan direction. Note the McCullough Abstract:

> In a scanning photolithographic device used in the manufacture of semiconductors, a method and apparatus for varying the exposure dose as a function of distance in the scan direction compensating for the signature of the photolithographic device for reducing linewidth variation in the scan direction. The linewidth in the scan direction may vary for a particular device or tool for a variety of reasons. This variation or signature is used in combination with a photosensitive resist response function to vary the exposure dose as a function of distance in a scan direction, substantially reducing the linewidth variation. A dose control varies the exposure dose as a function of distance in a scan direction to correct linewidth variations caused by characteristics of the photolithographic system. Linewidth variations as a function of distance in the direction of scan are substantially reduced, resulting in more consistent and improved feature or element sizes. (Emphasis added.)

Accordingly, McCullough relates to conventional semiconductor fabrication in which variations of linewidths are reduced by compensating the dose in exposing a photoresist. In fact, McCullough is designed to provide uniform linewidths by varying exposure dose, so that McCullough teaches away from (2) varying amplitude of a radiation beam to (5) image the array of microlenses, as recited in Claim 1. This is reinforced by the other cited passages of McCullough, such as Column 2, lines 29-31, and Column 6, lines 1-17. Thus, although McCullough teaches varying an amplitude of a scanned laser, it does so for totally different reasons in a totally different context.

The Office Action concedes in the middle of Page 4 that:

> The difference between the claims and Kodera in view of McCullough is that Kodera in view of McCullough does not disclose that the optical microstructures formed are an array of microlenses and that the microstructure master is a microlens array master.

Appellants have shown above that Kodera in view of McCullough fails to disclose much more than this. Nonetheless, in another unsuccessful attempt to supply the missing

teachings, the Office Action cites Raguin. However, Raguin clearly describes the use of positive photoresist, and clearly illustrates at Figure 8 that imaging through the substrate does not take place. Moreover, Raguin describes at Figures 8(a) and 8(b) the imaging through a mask **84**. Thus, Raguin describes the formation of microlenses as in the preamble of Claim 1 and uses a radiation beam, but does not supply any of the other missing teachings.

In summary, the Office Action appears to erroneously interpret the primary reference. In particular, Kodera provides flooding and uses mechanical molding to form various microstructures in a resin layer that is not even a photoresist. Light is merely used to flood the layer to enable it to be hardened and cured. Moreover, the new secondary reference McCullough teaches controlling an exposure dose as a function of distance in a scan direction to compensate for the signature of a photolithographic device, to thereby reduce linewidth variation in a semiconductor device and, accordingly, teaches away from varying the amplitude of the scanned radiation beam in order to image an array of microlenses. Accordingly, the primary and secondary references both teach away from combining certain known elements, so that discovery of a successful means of combining them by Appellants is more likely to be unobvious, as recently held by the U.S. Supreme Court. Moreover, although Raguin illustrates forming an array of microlenses, Raguin does not appear to provide any exposure through the substrate by scanning a radiation beam at varying amplitudes through a substrate into a negative photoresist layer on the substrate.

In conclusion, although Claim 1 is short, it recites five interrelated recitations that allow an array of microlenses to be fabricated. In an attempt to show obviousness, the Office Action has chosen three diverse references that individually teach away from their combination and, even if combined, do not suggest these five interrelated recitations. Thus, the Office Action has merely shown that the elements were individually independently known. However, they were known in such diverse environments that one of skill in the art would not somehow combine them to obtain the recitations of Claim 1 absent the hindsight that is provided by reading Claim 1. The fact that the prior art teaches away from the combination provides further evidence of unobviousness of Claim 1.

Appellants also wish to note that U.S. Patent Application Publication 2002/0034014 A1 to Gretton et al., assigned to Corning Incorporated, entitled *"Microlens Arrays Having High Focusing Efficiency"* (hereinafter "Gretton") provides secondary considerations of nonobviousness. This publication was cited in an Information Disclosure Statement filed June 29, 2004 and considered by the Examiner on October 26, 2006. This publication relates to fabricating an array of microlenses as does Claim 1. As noted in the Abstract of this publication:

> Microlens arrays (**105**) having high focusing efficiencies are provided. The high focusing efficiencies are achieved by accurately producing the individual microlenses making up the array at high fill factors. Arrays of positive microlenses are produced by forming a master having a concave surface-relief pattern (**101**) <u>in a positive photoresist (**21**) using direct laser writing</u>. Through this approach, the problems associated with the convolution of a finite laser beam with a desired profile for a microlens are overcome. The microlens arrays of the invention have focusing efficiencies of at least 75%. (Emphasis added.)

Thus, the Abstract points to the use of positive photoresists. As noted in Paragraph [0019] of Gretton:

> Processes for producing microlens arrays using direct laser writing in a photoresist are known in the art.... <u>The photoresist of choice for such processes is a positive photoresist since compared to negative photoresists, positive photoresists are more widely available, have been subject to more intensive research and development work by photoresist manufacturers, and generally have higher resolution</u>. However, as discussed in detail below, prior to the present invention, it has not been possible to produce arrays of positive microlenses having high focusing efficiencies at high fill factors using positive photoresists. (Emphasis added.)

Yet, despite this clear teaching in the prior art, Appellants have found that, indeed, negative photoresist can be used when the microlens arrays are imaged through a substrate that is transparent thereto. Moreover, as noted above, Applicants have found that backside imaging through a transparent substrate into negative photoresist can provide many advantages. For at least these additional reasons, independent Claim 1 is patentable over Kodera in view of McCullough and in further view of Raguin.

The dependent claims are patentable at least per the patentability of independent Claim 1 from which they all depend. Moreover, many of the dependent claims provide separate bases for patentability, as will be described below.

b. Dependent Claim 3

Dependent Claim 3 recites:

> 3. A method according to Claim 1 wherein the negative photoresist layer is thicker than the array of microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image a buried array of microlenses in the negative photoresist layer, adjacent the substrate.

Note the present application, Page 18, line 27-Page 19, line 19:

> As shown in Figure 16, some embodiments of the invention arise from the recognition that it may be difficult to form these shapes using conventional positive photoresist **1610** and conventional photoresist-incident ("front-side") exposure. In particular, as shown in Figure 16, when using positive photoresist **1610** and front-side exposure **1630** as is conventionally used, for example, in the semiconductor industry, the radiation acts as a "punch" to image the outer surface of the photoresist **1610** opposite the substrate **1600**. This relationship tends to form images **1620a**, **1620b** which are the opposite in shape as those which may be desired for optical microstructures (Figure 15). Moreover, as also shown in Figure 16, relatively shallow images **1620c** may exist only at the exposed surface of the photoresist layer **1610** and may be washed away during development. See, for example, Paragraphs 56-67 of the above-cited U.S. Published Patent Application 2002/0034014.
>
> In sharp contrast, as was shown, for example, in Figures 13A and 13B, back-side imaging combined with negative photoresist, according to some embodiments of the invention, can produce optical microstructures **132'** that include bases **1302** adjacent the substrate **800** and tops **1304** that are narrower than the bases **1302**, remote from the substrate **800**. Moreover, as shown in Figure 17, embodiments of the present invention that image through the substrate **800** and use negative photoresist **1310** can provide a photoresist layer **1310** that is thicker than the desired heights of the optical microstructures **1732**, so that the radiation beam may be impinged through the substrate **800** into the negative photoresist layer **1310** to image buried optical microstructures **1732** in the negative photoresist layer **1310**, adjacent the substrate **800**. As long as the negative photoresist layer **1310** is at least as thick as the thickest optical microstructure **1732** that is desired to be fabricated, relatively thick and relatively thin microstructures may be fabricated in one negative photoresist layer, adjacent the substrate **800**, and may not be washed away during the development process.

For at least these reasons, Claim 3 is independently patentable.

c. <u>Dependent Claim 4</u>

Dependent Claim 4 recites:

> 4. A method according to Claim 1 wherein at least some of the microlenses include a base and a top that is narrower than the base and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image the array of microlenses in the negative photoresist layer with the bases adjacent the substrate and the tops remote from the substrate.

The above-quoted portions of the specification from Pages 18-19 provide further proof of the independent patentability of Claim 4, as well.

d. <u>Dependent Claim 5</u>

Dependent Claim 5 recites:

> 5. A method according to Claim 1 wherein the negative photoresist layer is of variable thickness thereacross, wherein a minimum thickness of the negative photoresist layer is thicker than the microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image buried microlenses beneath the negative photoresist layer, adjacent the substrate, that are independent of the variable thickness of the negative photoresist layer.

The present application notes at Page 19, lines 20-28:

> Figure 18 illustrates other embodiments of the present invention that may use negative photoresist **1310** and imaging by a laser beam **822** through the substrate **800**. As shown in Figure 18, when forming a layer of negative photoresist **1310** over a large substrate **800**, the photoresist may have non-uniform thickness. However, as shown in Figure 18, as long as the minimum thickness of the negative photoresist layer **1310** is thicker than the optical microstructures **1832**, then buried optical microstructures **1832** may be imaged in the photoresist layer **1310** of variable thickness, adjacent the substrate **800**, that may be independent of the variable thickness of the negative photoresist layer **1310**.

The cited art does not describe or suggest any of these recitations. Accordingly, Claim 5 is also independently patentable.

e. <u>Dependent Claim 6</u>

Dependent Claim 6 recites:

> 6. A method according to Claim 1 wherein the negative photoresist layer includes impurities thereon, remote from the substrate, wherein the negative photoresist layer is thicker than the

> microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image buried microlenses in the negative photoresist layer, adjacent the substrate, that are not distorted by the impurities.

As described at Page 19, line 29-Page 20, line 4 of the present application:

> Other potential advantages of the use of back-side exposure and negative photoresist, according to some embodiments of the present invention, are shown in Figure 19. As shown in Figure 19, the negative photoresist layer **1310** may include impurities **1910** thereon. When using conventional front-side imaging rather than back-side imaging, these impurities **1910** may interfere with the front-side imaging. However, when using back-side imaging as shown in Figure 19, the laser beam **822** need not pass through or focus on, the outer surface **1310a** of the negative photoresist **1310**, remote from the substrate **800**. Thus, impurities **1910** need not impact the formation of optical microstructures **1832**. Accordingly, imaging may take place in a non-clean room environment in some embodiments of the present invention.

The recitations of Claim 6 are not described or suggested in the cited art, and the above-quoted portions of the specification provides evidence of independent patentability of Claim 6. Accordingly, Claim 6 is independently patentable.

f. <u>Dependent Claim 8</u>

Dependent Claim 8 recites:

> 8. A method according to Claim 1 wherein the negative photoresist layer is on a cylindrical platform such that the substrate is on the negative photoresist layer remote from the cylindrical platform, and wherein scanning comprises:
>
> rotating the cylindrical platform about an axis thereof while simultaneously axially rastering the radiation beam at varying amplitude through the substrate that is on the cylindrical platform across at least a portion of the negative photoresist layer to image the array of microlenses in the negative photoresist layer.

The Office Action has cited McCullough as describing scanning/rotating. However, as was already described above, McCullough teaches controlling an exposure dose as a function of distance in a scan direction to compensate for the signature of the photolithographic device, to thereby reduce linewidth variation in a semiconductor device and, accordingly, teaches away from varying amplitude of the scanned radiation beam in order to image an array of microlenses. Accordingly, Claim 8 is independently patentable.

g. Dependent Claims 7, 9, 10 and 15-18

Dependent Claims 7 and 15-18 are patentable as per the patentability of independent Claim 1 from which they depend. Dependent Claims 9 and 10 are patentable as per the patentability of dependent Claim 8 from which they depend.

III. Claims 11-13 Are Unobvious Over Kordera In View of McCullough and Raguin, and Further In View of Adler and Georger

Dependent Claims 11-13 are patentable as per the patentability of independent Claim 1 from which they depend.

III. Conclusion

As shown above, Appellants have discovered unique methods of fabricating arrays of microlenses. The claimed invention can provide unique advantages, as was described throughout the application. The Office Action continues to selectively pick and choose various features from different patents, despite their teachings, and teachings away, in an unsuccessful and impermissible attempt to reconstruct the claimed invention. For at least these reasons, Appellants respectfully request withdrawal of the rejection of independent Claim 1. Moreover, Appellants have also shown that many of the dependent claims are separately patentable.

In light of the above discussion, Appellants submit that the pending claims are directed to patentable subject matter and, therefore, request reversal of the rejections of the claims and passing of the application to issue.

It is not believed that an extension of time and/or additional fee(s) are required, beyond those that may otherwise be provided for in documents accompanying this paper. In the event, however, that an extension of time is necessary to allow consideration of this paper, such an extension is hereby petitioned for under 37 C.F.R. §1.136(a). Any

additional fees believed to be due in connection with this paper may be charged to Deposit Account No. 50-0220.

Respectfully submitted,

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CERTIFICATION OF TRANSMISSION

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with § 1.6(a)(4) to the U.S. Patent and Trademark Office on May 7, 2008.

Susan E. Freedman
Date of Signature: May 7, 2008

APPENDIX A
Pending Claims U.S. Serial No. 10/661,917
Filed September 11, 2003

1. (Previously Presented) A method of fabricating an array of microlenses comprising:

scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image the array of microlenses in the negative photoresist layer.

2. (Canceled)

3. (Previously Presented) A method according to Claim 1 wherein the negative photoresist layer is thicker than the array of microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image a buried array of microlenses in the negative photoresist layer, adjacent the substrate.

4. (Previously Presented) A method according to Claim 1 wherein at least some of the microlenses include a base and a top that is narrower than the base and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image the array of microlenses in the negative photoresist layer with the bases adjacent the substrate and the tops remote from the substrate.

5. (Previously Presented) A method according to Claim 1 wherein the negative photoresist layer is of variable thickness thereacross, wherein a minimum thickness of the negative photoresist layer is thicker than the microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image buried microlenses beneath the negative photoresist layer, adjacent the substrate, that are independent of the variable thickness of the negative photoresist layer.

6. (Previously Presented) A method according to Claim 1 wherein the negative photoresist layer includes impurities thereon, remote from the substrate,

wherein the negative photoresist layer is thicker than the microlenses and wherein scanning comprises scanning a radiation beam at varying amplitude through a substrate that is transparent thereto into a negative photoresist layer on the substrate to image buried microlenses in the negative photoresist layer, adjacent the substrate, that are not distorted by the impurities.

7. (Original) A method according to Claim 1 wherein the substrate is a flexible substrate.

8. (Previously Presented) A method according to Claim 1 wherein the negative photoresist layer is on a cylindrical platform such that the substrate is on the negative photoresist layer remote from the cylindrical platform, and wherein scanning comprises:

rotating the cylindrical platform about an axis thereof while simultaneously axially rastering the radiation beam at varying amplitude through the substrate that is on the cylindrical platform across at least a portion of the negative photoresist layer to image the array of microlenses in the negative photoresist layer.

9. (Original) A method according to Claim 8 further comprising simultaneously translating the cylindrical platform and/or radiation beam axially relative to one another.

10. (Previously Presented) A method according to Claim 9 further comprising simultaneously continuously varying the amplitude of the radiation beam.

11. (Original) A method according to Claim 1 wherein the substrate is at least about one square foot in area.

12. (Previously Presented) A method according to Claim 1 wherein scanning is performed continuously on the substrate for at least about 1 hour.

13. (Previously Presented) A method according to Claim 1 wherein scanning is performed continuously on the substrate for at least about 1 hour to fabricate at least about one million microlenses.

14. (Canceled)

15. (Previously Presented) A method according to Claim 1 further comprising:

developing the microstructures that are imaged in the negative photoresist layer to provide a microlens array master.

16. (Original) A method according to Claim 1 wherein the substrate is cylindrical, ellipsoidal or polygonal in shape.

17. (Previously Presented) A method according to Claim 1 further comprising translating the substrate and/or radiation beam relative to one another while scanning the radiation beam.

18. (Previously Presented) A method according to Claim 15 further comprising:

forming a plurality of second generation stampers directly from the master; and

forming a plurality of third generation microlens array end products directly from a stamper.

19.-105. (Canceled)

APPENDIX B – EVIDENCE APPENDIX

U.S. Patent Application Publication 2002/0034014 to Gretton et al., cited by Applicants in Appellants' Information Disclosure Statement filed June 29, 2004, considered by the Examiner October 26, 2006 and attached to an Office Action mailed November 14, 2006.

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(54) MICROLENS ARRAYS HAVING HIGH FOCUSING EFFICIENCY

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(22) Filed: **Jul. 30, 2001**

Related U.S. Application Data

(63) Non-provisional of provisional application No. 60/222,032, filed on Jul. 31, 2000. Non-provisional of provisional application No. 60/222,033, filed on Jul. 31, 2000.

Publication Classification

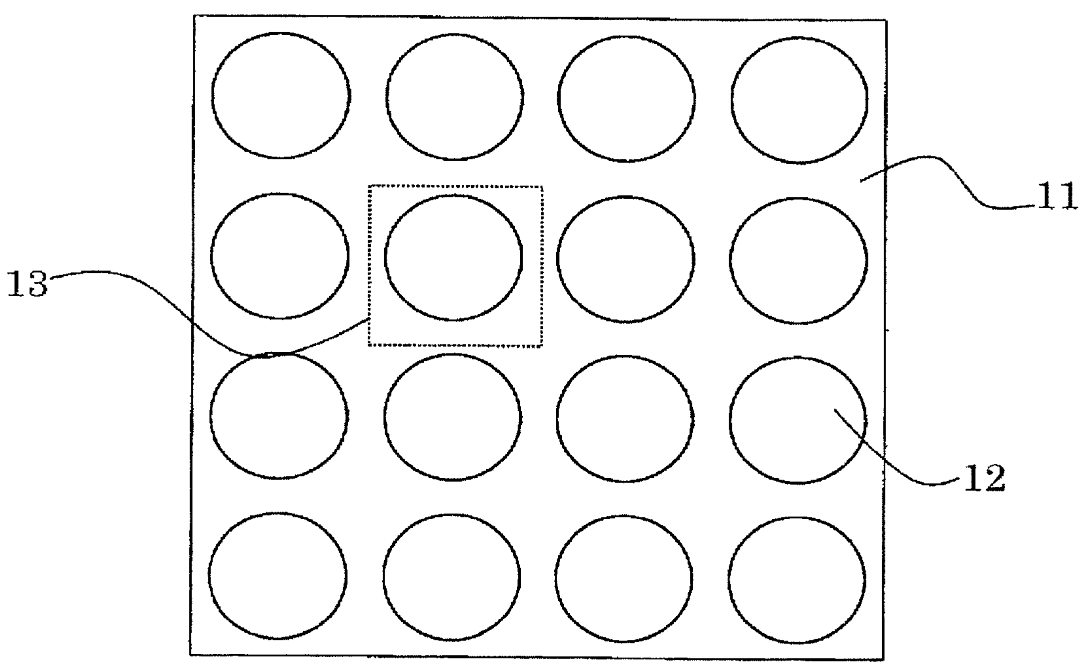
(51) Int. Cl.[7] **G02B 27/10**

(52) U.S. Cl. **359/619**; 359/620; 359/621

(57) **ABSTRACT**

Microlens arrays (**105**) having high focusing efficiencies are provided. The high focusing efficiencies are achieved by accurately producing the individual microlenses making up the array at high fill factors. Arrays of positive microlenses are produced by forming a master having a concave surface-relief pattern (**101**) in a positive photoresist (**21**) using direct laser writing. Through this approach, the problems associated with the convolution of a finite laser beam with a desired profile for a microlens are overcome. The microlens arrays of the invention have focusing efficiencies of at least 75%.

44% fill-factor



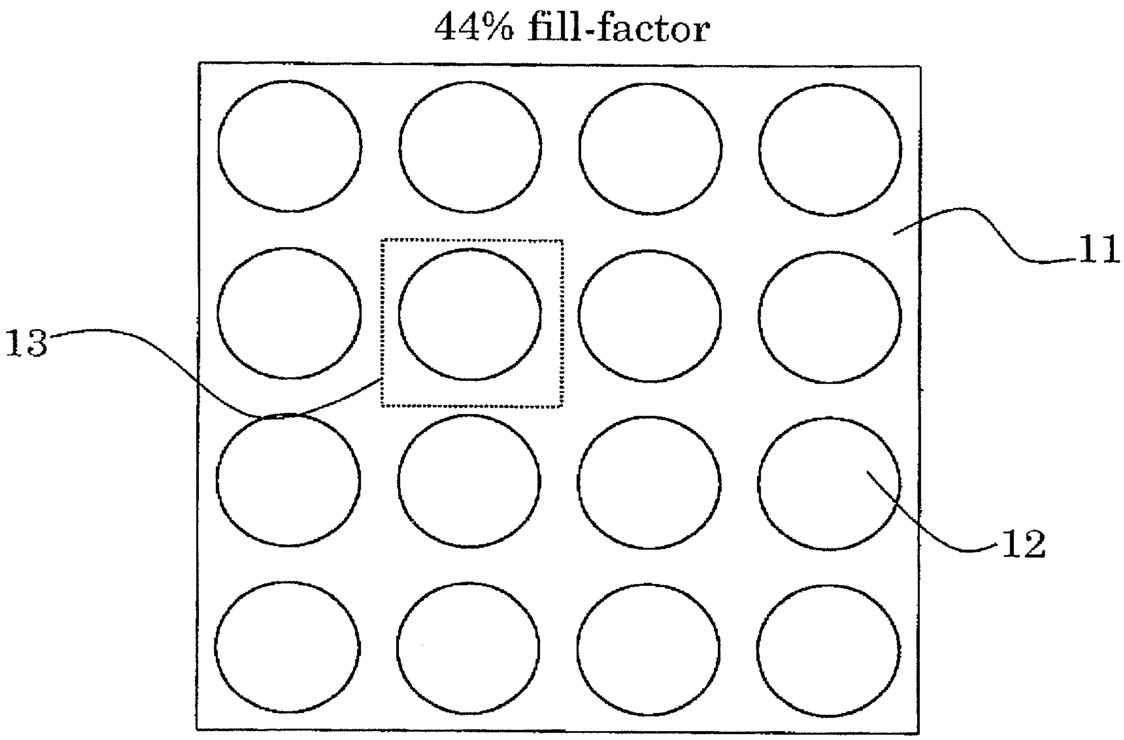


FIG. 1

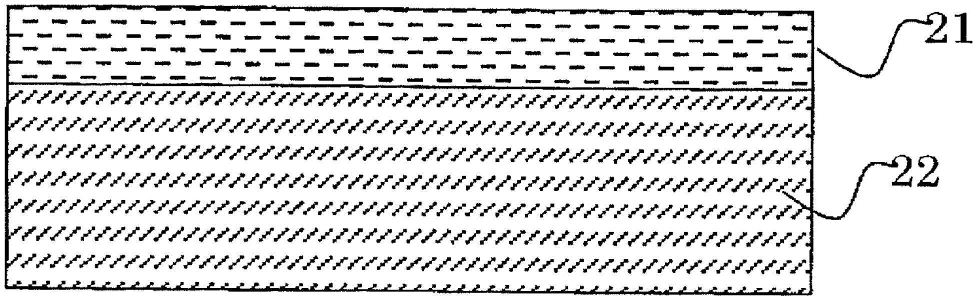


FIG. 2

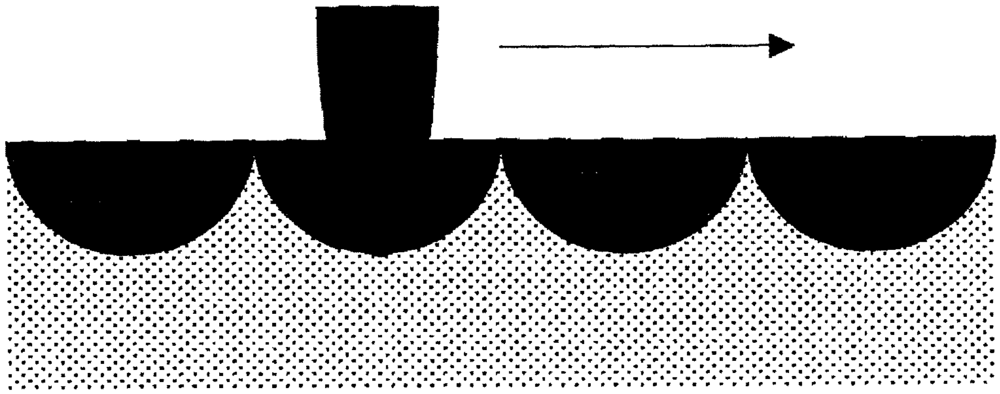


FIG. 3

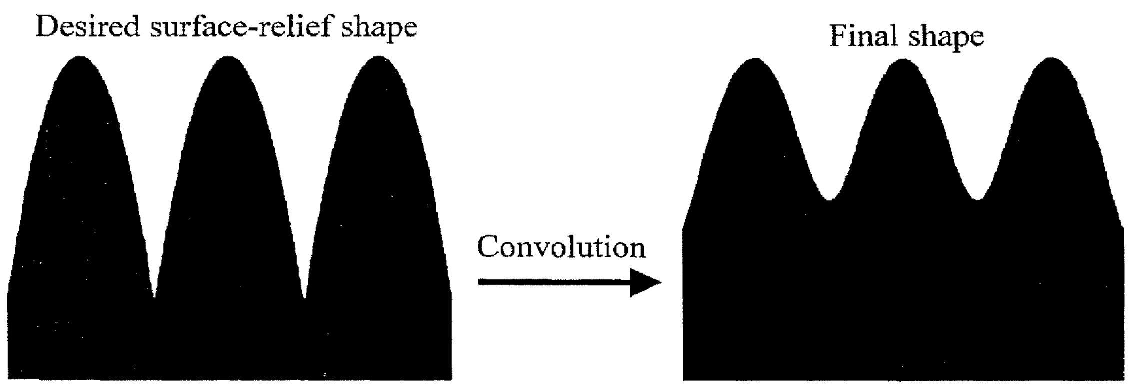

Desired surface-relief shape
Convolution
Final shape

FIG. 4A

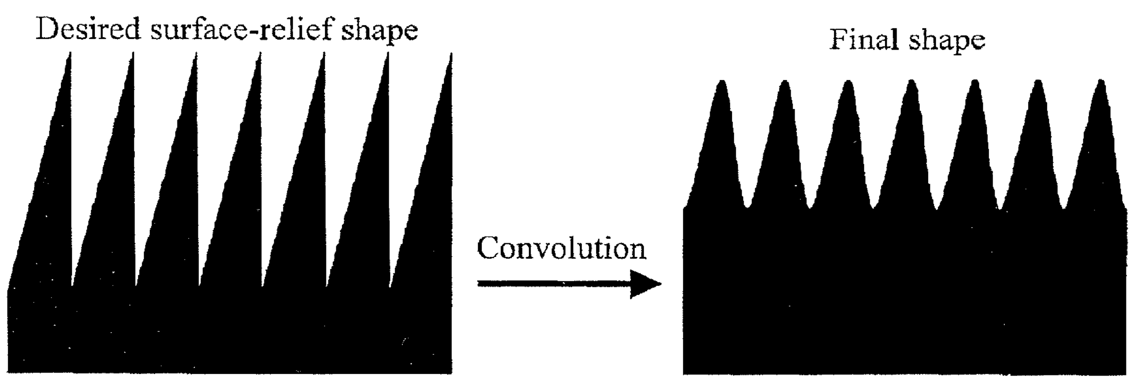

Desired surface-relief shape
Convolution
Final shape

FIG. 4B

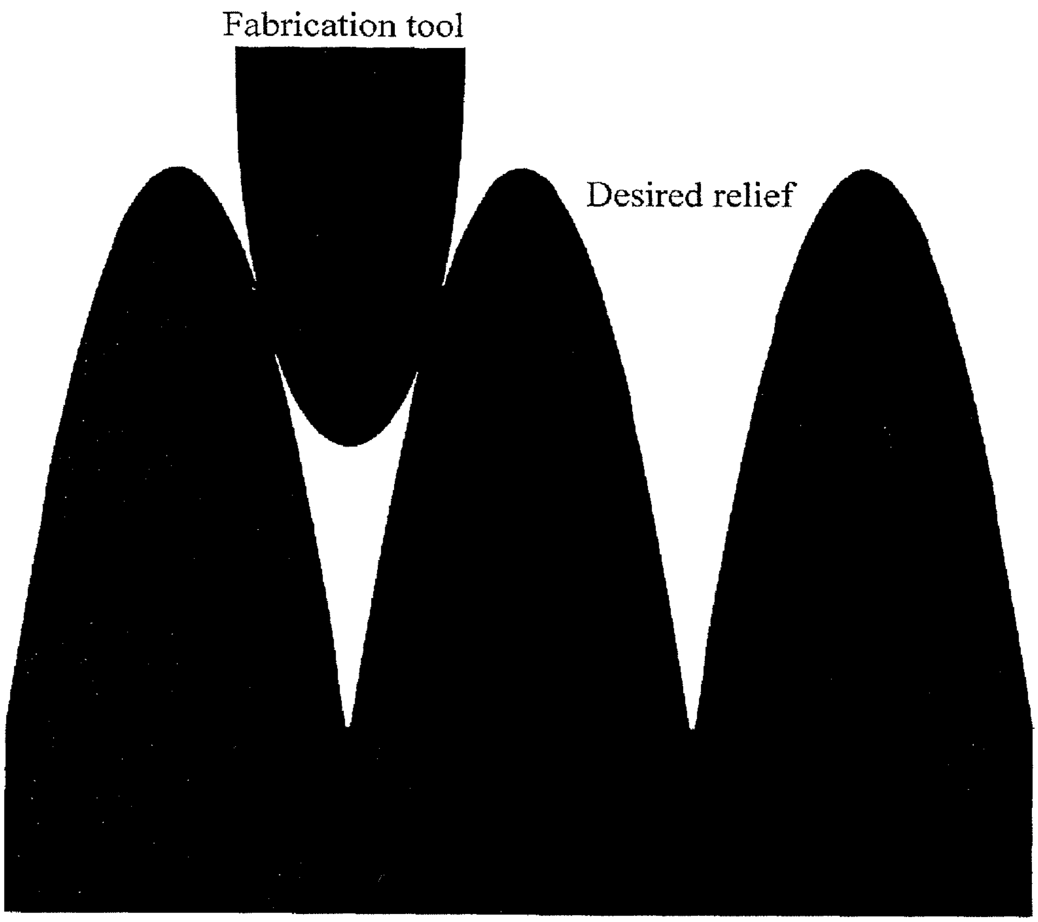


FIG. 5A

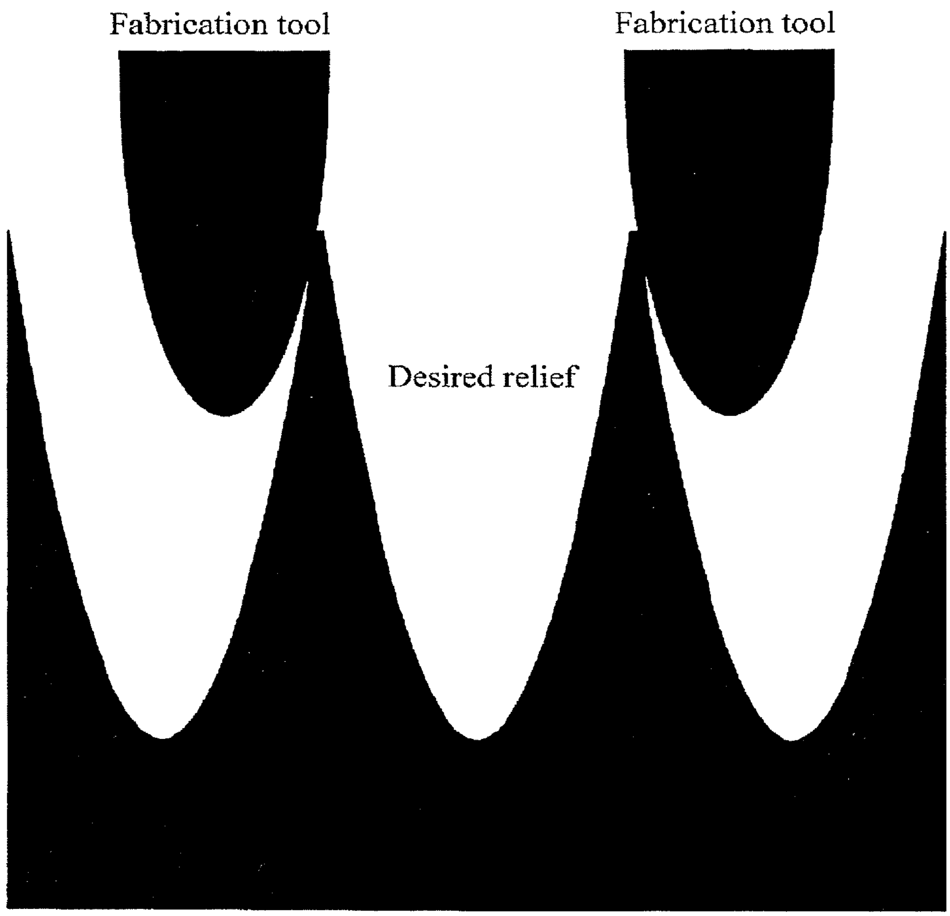


FIG. 5B

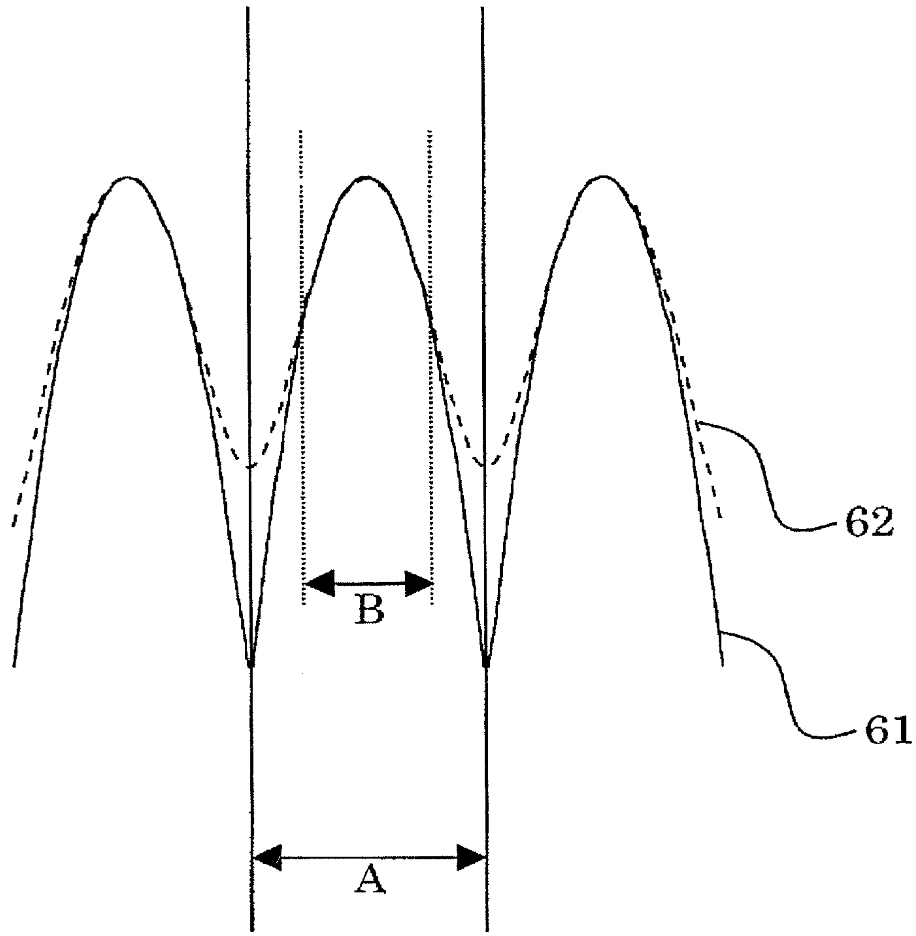


FIG. 6

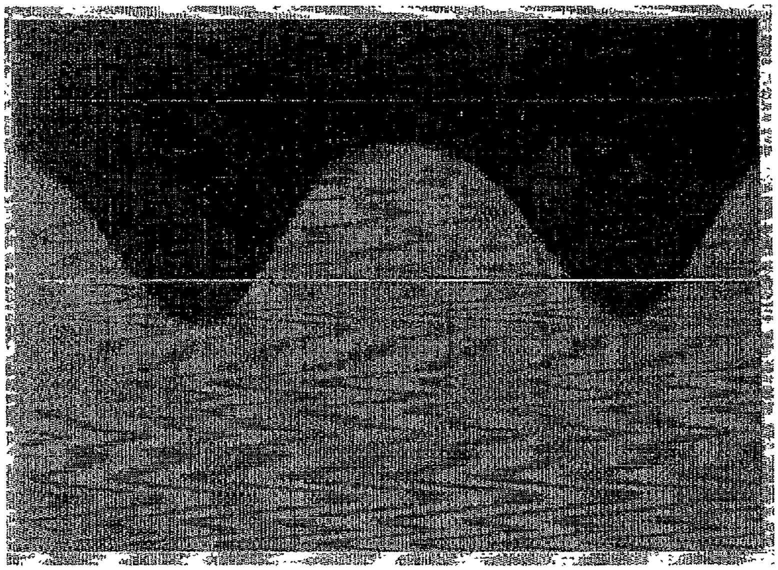


FIG. 7A

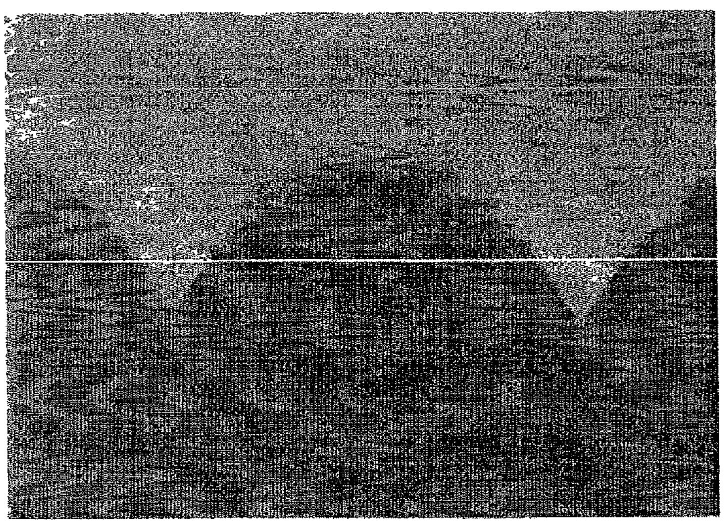


FIG. 7B

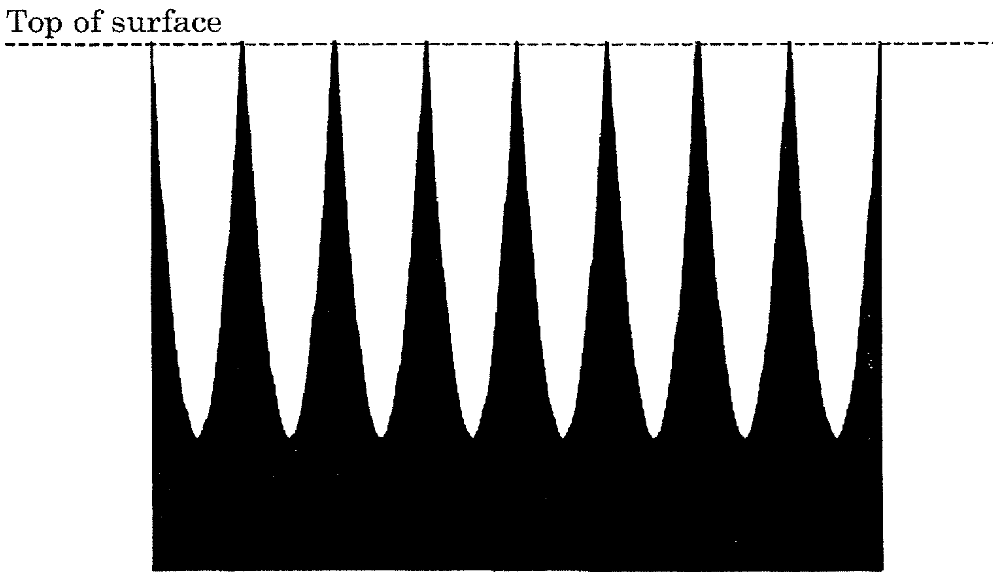


FIG. 8

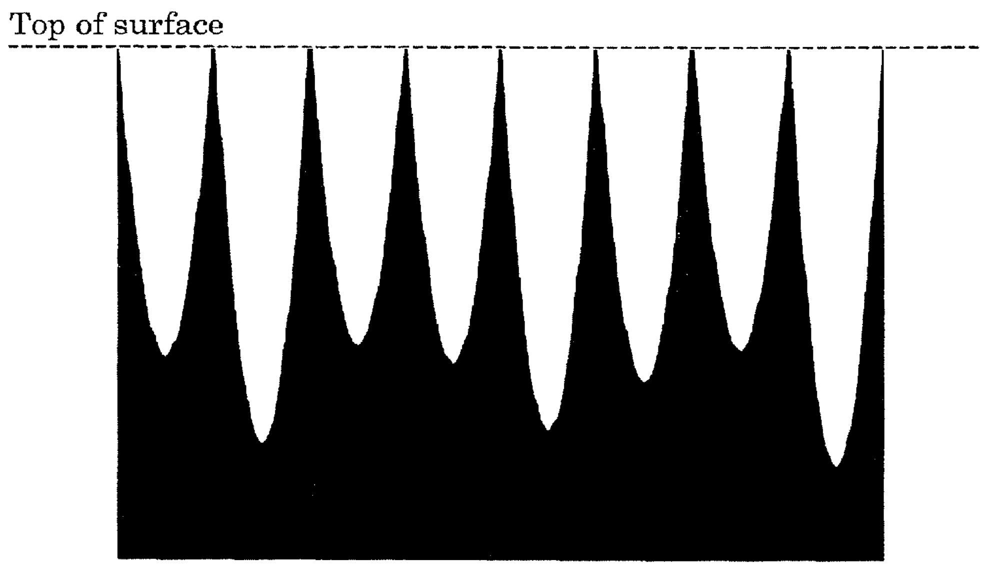


FIG. 9

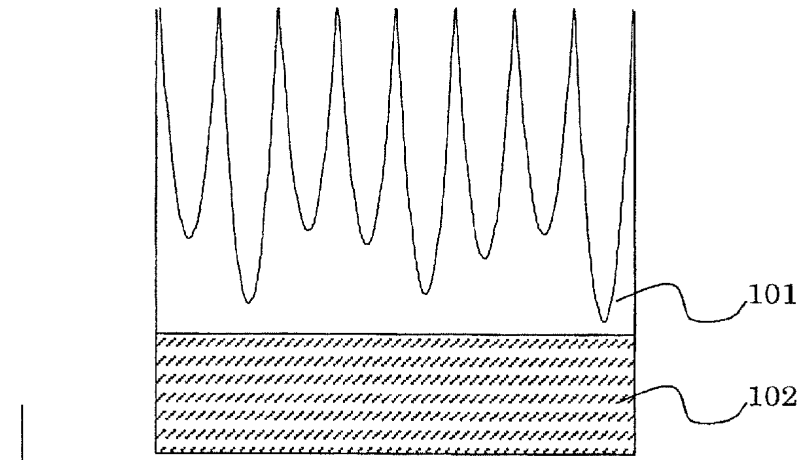


FIG. 10A

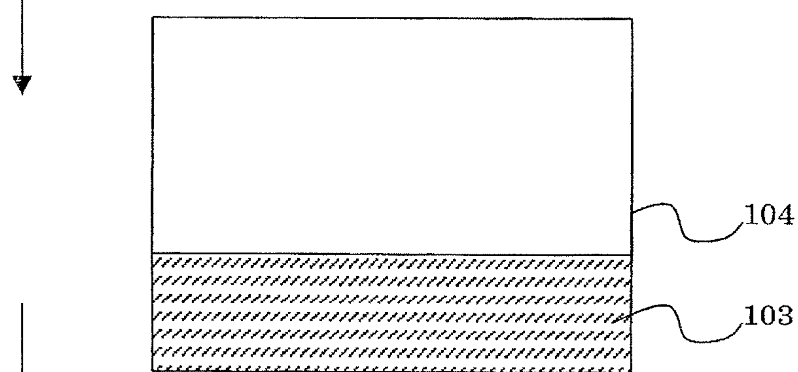


FIG. 10B

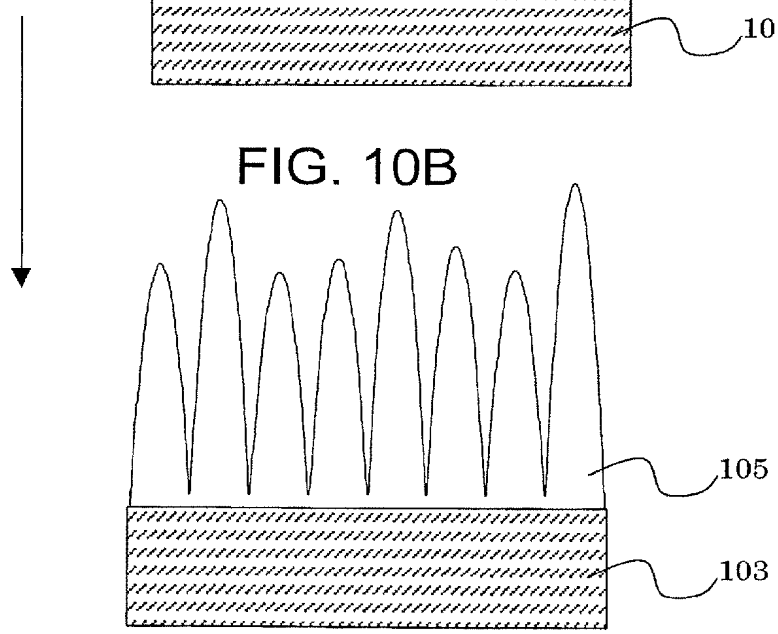


FIG. 10C

MICROLENS ARRAYS HAVING HIGH FOCUSING EFFICIENCY

I. FIELD OF THE INVENTION

[0001] The present invention relates to arrays of microlenses having high focusing efficiencies. It also relates to methods for fabricating such arrays.

[0002] The invention is applicable to the efficient focusing of laser light into optical fibers, light diffusion, and controlled scattering of coherent or incoherent light for projection and transmissive displays, among other applications.

II. DEFINITIONS

[0003] The following definitions are used herein:

[0004] A "microlens array" is an array of microlenses and an associated array of unit cells, with one microlens being associated with each unit cell. The microlenses of the present invention can have any desired configuration and can be formed on, for example, a supporting "piston" of the type disclosed in commonly assigned U.S. patent application Ser. No. 60/222,033 which is being filed concurrently herewith in the names of G. Michael Morris and Tasso R. M. Sales and is entitled "Structured Screens for Controlled Spreading of Light," the content of which in its entirety is incorporated herein by reference. Thus, as used herein, the term "microlens" means any microstructure which is capable of focusing light.

[0005] The "fill factor" of a microlens array is the ratio of the sum of the areas within the unit cells occupied by microlenses to the sum of the areas of the unit cells.

[0006] The "focusing efficiency" of a microlens array is the sum of the measured light intensities at the focal points of the microlenses divided by the sum of the light intensities impinging on the unit cells of the array for an array illuminated along its optical axis by a collimated, substantially spatially incoherent light source, e.g., a collimated white light source. As will be recognized by those skilled in the art, this is a "Strehl-type" definition of focusing efficiency.

[0007] Since concave microlenses will typically have virtual focal points (e.g., a plano-concave microlens in air will have a negative power and thus a virtual focal point for collimated light), an auxiliary optical system needs to be used in such cases to produce real focal points whose intensities can be measured. To at least some extent, the auxiliary optical system will reduce the intensities at the real focal points, and those reductions should be taken into account in determining the intensity values for the virtual focal points.

[0008] In the case of anamorphic microlenses, the light intensities at each of the focal points of the microlens are included in the sum of the measured light intensities.

III. BACKGROUND OF THE INVENTION

[0009] Microlenses are required in many applications, such as light coupling from lasers to fibers, either as single lenses or in array form whereby several beams are focused to several fibers. Other important applications include light diffusion and screens.

[0010] Depending on the application, one may require a microlens of accurate profile with controlled focusing properties or, in the case of an array, high quality over most lenses in the array. To focus light efficiently, the lens profile (or sag function) must be fabricated with accuracy typically equal to or better than, for example, $\lambda/4$, where λ is the wavelength of the illumination source.

[0011] In addition, particularly for high-density coupling, diffusion, or screen applications, it is often important that the microlenses utilize the entire surface for focusing. In this way, essentially all incident light can be controlled by the array. When the entire useful surface area is employed for focusing, the array is said to possess a 100% fill factor.

[0012] Close packing of microlenses implies a fill factor equal to 100%, which means that the internal boundaries between neighboring microlenses are in close contact. A simple example of close packing is a hexagonal array. Other arrangements, such as square arrays, can also be close packed.

[0013] It is typical to find in both the scientific and patent literature arrays of microlenses that have fill factors below 100%. **FIG. 1** illustrates such an array where microlenses **12** are regularly placed on the available substrate area **11** with spaces being left between the individual microlenses. One of the unit cells of the array of **FIG. 1** is shown by dashed lines **13**. The fill factor for this array is only 44%.

[0014] There are several existing methods for fabricating isolated microlens units or arrays of microlenses whose edges are well-separated so that their boundaries avoid close contact. Because there is a finite distance between the internal boundaries of neighboring lenses, the fill factor for the array is necessarily less than 1 (or 100%).

[0015] The difficulty in obtaining efficient closed-packed lens arrays using prior art fabrication methods is due to the inability of those methods to preserve the boundaries of microlenses accurately, particularly for small and strongly focusing lenses.

[0016] Methods using thermal deformation, such as that disclosed in U.S. Pat. No. 5,324,623, are based on volume relaxation and thus cannot control the fusing of material at the internal boundaries between microlenses. With fusion there is distortion that reduces focusing capabilities. Thermal deformation methods are simple to implement but allow limited control of the individual microlens structures.

[0017] Other methods, such as those described in U.S. Pat. No. 5,300,623, involve the creation of mechanical molds that define receptacles for curable liquids. The liquid is poured into the receptacles and the natural surface tension creates a bowed surface that serves as the microlenses. The mold, with the various receptacles, defines the array arrangement. Due to the inherent limitation of this method in controlling the shape of the microlens units, its efficiency cannot be optimized for a general application. Other mechanical methods based on the direct ruling of individual microlenses, such as diamond turning, are better suited for the fabrication of individual microlenses rather than arrays.

[0018] Methods based on ion diffusion processes that provide gradient-index arrays, such as those described in U.S. Pat. No. 5,867,321, cannot provide a 100% fill factor, with the region between two neighboring microlenses being

typically 20% of the microlens repetition spacing. Gradient-index arrays present a serious limitation for large-volume fabrication due to the intrinsically slow diffusion process.

[0019] Processes for producing microlens arrays using direct laser writing in a photoresist are known in the art. See commonly-assigned PCT Patent Publication No. WO 99/64929, Gale et al., U.S. Pat. No. 4,464,030, and *Micro-Optics: Elements, systems and applications*, Hans P. Herzig, ed., Taylor & Francis, Bristol, Pa., 1997, pp. 53-152. The photoresist of choice for such processes is a positive photoresist since compared to negative photoresists, positive photoresists are more widely available, have been subject to more intensive research and development work by photoresist manufacturers, and generally have higher resolution. However, as discussed in detail below, prior to the present invention, it has not been possible to produce arrays of positive microlenses having high focusing efficiencies at high fill factors using positive photoresists.

[0020] The present invention addresses the difficulties associated with the prior art by providing methods for fabricating microlens arrays having high focusing efficiencies through accurate microlens fabrication at high fill factors. The array can be arranged in any arbitrary way, such as square, hexagonal, or random. In addition, the methods allow the fabrication of microlenses of arbitrary shape as well as variable focusing power for different directions (anamorphic lenses).

IV. SUMMARY OF THE INVENTION

[0021] In view of the foregoing, the objects of the invention include at least some and preferably all of the following:

[0022] (1) the provision of fabrication methods for producing arrays of convex microlenses having high focusing efficiencies;

[0023] (2) the provision of arrays of convex and/or concave microlenses with greater than 75% focusing efficiency, preferably greater than 85% focusing efficiency, and most preferably greater than 95% focusing efficiency;

[0024] (3) the provision of methods for accurately fabricating arrays of convex microlenses at high fill factors; and/or

[0025] (4) the provision of arrays of accurately fabricated convex and/or concave microlenses with fill factors greater than 90%, preferably greater than 95%, and most preferably approximately 100% so that the entire useful area of a substrate can be employed for focusing or, more generally, scattering of an illuminating beam.

[0026] In connection with these objects, it is also an object of the invention to allow the microlenses of the array to have arbitrary shapes (sag functions) that can vary randomly within the array.

[0027] It is a further object of the invention to provide improved methods for using positive photoresists to produce arrays of convex microlenses at high fill factors.

[0028] To achieve the foregoing and other objects, the invention provides a fabrication method for producing an array of convex microlenses wherein direct laser writing is used to produce an initial master (initial mold) in a positive photoresist wherein the surface configuration of the initial master is the negative (complement) of the desired array of convex microlenses. That is, the initial master has a concave, instead of a convex, surface configuration. In this way, as discussed in detail below, the problems caused by the finite size of a laser beam and the convolution of such a beam with the desired profile(s) of convex microlenses are overcome. By overcoming these problems, convex microlens arrays having high focusing efficiencies are achieved.

[0029] In general, a high focusing efficiency for an array of microlenses depends on two factors: (1) a high fill factor, and (2) accurate reproduction of the desired lens profiles. Both factors are necessary and neither factor alone is sufficient.

[0030] Thus, a high fill factor can be achieved by a process that alters all parts of a resist film, but if the alterations do not correspond to the desired lens profiles, the focusing efficiency of the array will still suffer since the parts of the resist film that have the inaccurate profiles will not focus incident light properly. On the other hand, accurate reproduction of a desired lens profile with the individual microlenses spaced far apart also results in low focusing efficiency, in this case as a result of light passing through the spaces between microlenses.

[0031] In accordance with the invention, it has been found that both factors can be addressed by using the concave form to initially write convex lenses in a positive photoresist. In this way, high focusing efficiency through the accurate production of desired lens profiles at a high fill factor is achieved.

[0032] In accordance with certain preferred embodiments, the invention is practiced by using a substrate typically made of glass to support a first medium to generate an initial master (initial mold), which is later used to accurately replicate the desired microlens array in a cost-effective fashion. More particularly, a photosensitive positive resist film is deposited on the substrate to an appropriate thickness consistent with the desired thickness for the final microlens array. The positive resist is preferably of the low-contrast kind such that, when exposed to light, a smoothly varying surface-relief profile can be produced.

[0033] After being deposited on the substrate, the positive resist is exposed to a laser beam having a well-characterized profile. With a pre-defined sampling rate, the area of the resist film of interest is exposed to the laser beam. By varying the intensity of the beam, the complement of the shape of each microlens in the array is encoded in the resist. In particular, the laser exposure produces a latent image in the photosensitive film by modifying its physical and chemical properties.

[0034] Next, the film is developed to produce a surface-relief structure. For a resist film of the positive kind, development removes the exposed area leaving the unexposed regions. The above combinations of surface-relief structure and photoresist type for the initial master are critical aspects of the invention since only through the indicated combinations can high focusing efficiencies be achieved through high fill factors and minimized convolution effects of a finite laser beam.

[0035] It has been generally believed in the art that the convolution effects of a finite laser beam would be essen-

tially the same irrespective of whether the laser beam exposure created a convex or concave surface-relief structure. In accordance with the invention, it has been found that this belief is not true and in fact by fabricating the initial master for a convex microlens array as a concave surface-relief structure, high fill factors (e.g., fill factors equal to or essentially equal to 100%) and high focusing efficiencies (e.g., focusing efficiencies at least above 75%) are achieved. A detailed discussion of how this combination addresses the convolution problem is presented below.

[0036] To create a mold usable in high volume replication, intermediary replication steps are generally necessary because resist films are usually unsuitable for large-volume replication. For example, the concave surface-relief structure can be used to prepare an intermediate master (intermediate mold), which is of convex form. The intermediate master can then be replicated once more to provide a final master (final mold), now in concave form. Large-volume replication is then possible with the final concave master so that the final array has a convex form and provides a high fill factor and a high focusing efficiency.

[0037] The array need not be limited to regularly periodic arrangements, such as square or hexagonal arrays, but may assume any general arbitrary form, as dictated by the requirements of the design. Furthermore, the lens shape need not be the same and can, in fact, vary for every microlens in the array. For example, the techniques of the present invention can be used to produce the configurations and distributions of microstructures set forth in the above-referenced, commonly assigned U.S. Patent Application entitled "Structured Screens for Controlled Spreading of Light."

[0038] A fact of importance in the present invention is that the tops of the concavities of the concave surface-relief structure formed in the positive resist film are preferably aligned or vary slowly for any neighboring elements. If this guideline is not satisfied, accurate profiles may only be produced over a portion of the array, reducing both the fill factor and the focusing efficiency of the array.

V. BRIEF DESCRIPTION OF THE DRAWINGS

[0039] **FIG. 1** is a top view of a lens array with a fill factor less than 100%.

[0040] **FIG. 2** shows a glass substrate with a photosensitive film deposited on its surface.

[0041] **FIG. 3** shows the scanning of a laser beam over a photosensitive film creating a region of distinct chemical properties (latent image).

[0042] **FIG. 4A** and **FIG. 4B** show the effect of convolution in the fabrication of convex structures.

[0043] **FIG. 5A** and **FIG. 5B** illustrate the interaction of a hard fabrication tool in relation to a convex and concave array, respectively.

[0044] **FIG. 6** illustrates a technique for estimating the focusing efficiency of the microlens units of an array fabricated in convex form.

[0045] **FIG. 7A** and **FIG. 7B** show experimental plots of identical microlens profiles fabricated in convex and concave forms, respectively.

[0046] **FIG. 8** and **FIG. 9** illustrate surface-relief structures having concave cavities formed in a positive photoresist where the edge boundaries of the cavities are aligned with the top surface of the photoresist.

[0047] **FIG. 10A**, **FIG. 10B**, and **FIG. 10C** illustrate the replication of an initial mold having concave cavities to obtain a final array of convex microlenses.

VI. DETAILED DESCRIPTION OF THE INVENTION

[0048] Referring now to the figures, **FIG. 2** shows a photosensitive resist film **21** of low contrast deposited on a substrate **22** which is typically made of glass. The thickness of the film should be equal to or larger than the total depth span defined by the lens array. Depending on the total thickness of the array, the resist may require preliminary processing such as hardening.

[0049] After the initial resist processing, a laser beam is focused at the resist film and scanned along the surface so as to expose the whole resist surface, as indicated in **FIG. 3**. The intensity of the laser beam varies for every point in such a fashion that a latent image of the negative of the desired convex microlenses is imprinted in the resist in the form of a chemical transformation of the resist material.

[0050] To obtain a surface-relief structure the chemically modified resist film undergoes a development process, which consists of exposure to a solution of, for example, a standard alkali developer for a period of time that varies with the total thickness of the array. Deeper arrays require longer development times. For a resist of the positive type, the development process removes the exposed areas, leaving the unexposed areas.

[0051] According to the inventive process described herein, each microlens in the array needs to be produced in the positive photoresist in concave form. Only in this way is it possible to reduce significantly the rounding effect observed when microlenses are fabricated in convex form. This is so because the fabrication process itself introduces features into a surface-relief profile that are undesirable.

[0052] Given the mathematical description of the desired surface-relief structure and the writing laser beam, the relief structures obtained by exposure of a resist film are generally described as the convolution of the desired surface function with the laser beam function. The operation of convolution can be mathematically described by the following relation:

$$F(x, y) = \int_S \int f(x', y') g(x' - x, y' - y) dx' dy', \tag{1}$$

[0053] where f represents the mathematical function describing the desired surface relief, g represents the mathematical form of the writing laser beam, S represents the fabricated surface area, (x,y) denotes a point on the surface of the photosensitive film, and F represents the final surface shape.

[0054] The validity of Eq. (1) relies on the assumption that the interaction of the laser beam and the photosensitive film is linear, in the sense that the response of the film is in direct proportionality to the intensity of the laser exposure and that

the superposition of several beams has a simple additive effect. To a good approximation this assumption is correct and can be observed in surface-relief structures fabricated in convex form, that is, structures that protrude from the resist surface as illustrated in **FIGS. 4A and 4B**.

[0055] The fact that the expected convolution effects are readily observed in convex structures has led to the general belief that the same type of behavior would happen for concave shapes. In fact, if one uses Eq. (1), and notes that to obtain the concave shape one simply needs to multiply the convex shape by −1 and add a constant, then it would appear that the final shape should be the same for both the concave and the convex shapes, except for the change in sign.

[0056] However, it turns out that the interaction between the laser beam and the photosensitive film is not linear and, therefore, the convolution relation can describe the fabrication process only approximately. In fact, in accordance with the invention, we have discovered that the laser writing process is more akin to the fabrication of devices by means of hard mechanical apparatuses such as diamond tools.

[0057] In such fabrications, convolution effects are still present but they are of a different nature than those observed with a laser beam because latent image-formation is non-existent and superposition effects do not occur. It is the contact of the mechanical tool with the surface being ruled that creates the surface relief. There is, however, an intrinsic asymmetry in the mechanical fabrication of convex and concave structures. Because of the finite size of the tool, it is not possible to penetrate the narrow region between two neighboring structures, but there is no difficulty in creating the sharp contact point of two concave structures. This is illustrated in **FIGS. 5A and 5B**.

[0058] In accordance with the invention, we have found that the laser writing process operates according to similar principles and exhibits similar asymmetry when considering convex and concave shapes. This surprising result enables the fabrication of fully-packed convex microlens arrays, as opposed to previous methods that can only guarantee accurate profiles over a fraction of the aperture of the array in a fully-packed arrangement.

[0059] Importantly, the laser-writing process when used to make concave surface-relief structures not only achieves the advantage of mechanical ruling devices for concave structures but also offers significant capabilities that go beyond those of mechanical ruling methods. For instance, there is virtually no limitation regarding the size or shape of microlenses made with the laser-writing process. Also, the size of the mechanical tool itself determines the extent of the boundary region between neighboring microlenses. With laser writing, this region can be arbitrarily reduced.

[0060] The ability to preserve a concave surface-relief shape from the apex of the structure to its very edge at the boundary of a neighboring concavity allows for the fabrication of arrays of convex microlenses of high focusing efficiency. It does so since it allows the final convex microlenses to have a fully-packed arrangement. In contrast, if the array is directly produced in convex form, independent of whether one uses a mechanical tool, a laser tool, or other process, the boundaries of two neighboring microlenses cannot be usefully employed for focusing and thus the array will have a reduced focusing efficiency.

[0061] This deficiency of producing an array in convex form, whether by means of a mechanical or a laser tool, is illustrated in **FIG. 6**. In this figure, the desired microlens shape is represented by curve **61** with an area available for focusing represented by the parameter A. However, due to the fabrication, the actual microlens shape turns out be that given by curve **62** and the area available for focusing now being represented by the parameter B. The observed rounding effect at the boundaries of the microlenses diverts the incident illumination to locations other than the focal point of the microlens. Therefore, only area B becomes available for focusing. In this way, the estimated focusing efficiency of the microlens η can be written as

$$\eta = \left(\frac{B}{A}\right)^2 \times 100\%. \tag{2}$$

[0062] With the prior art, B is always less than A so that the focusing efficiency is less than 100%. With the current inventive process, the initial surface-relief structure is written in concave form so that sharp boundaries between lenses are well reproduced in the final microlens array. When the concave master is replicated one obtains a convex array such that B essentially equals A. Consequently the focusing efficiency is essentially 100%.

[0063] Experimental studies have confirmed the above analysis, especially in the case of convex microlenses of high numerical aperture (fast lenses) where light is focused at large angles. **FIG. 7A** shows the case of an array of microlenses with diameter equal to 50 μm fabricated in convex mode. The boundaries between microlenses are clearly rounded and cannot be efficiently used for focusing. The estimated efficiency for each microlens in this array is 50%.

[0064] On the other hand, when the same array is fabricated in concave form one obtains a far better result, as shown in **FIG. 7B**. Note that the boundaries are preserved. This array is estimated to be 100% efficient in focusing. In addition the concave surface-relief structure can be fully packed without losing efficiency. Direct writing of a convex array cannot achieve such packing without loss of efficiency.

[0065] As another important component of the present inventive process, the concavities of the concave surface-relief structure formed in the positive photoresist should have their extremities aligned with the surface of the resist as indicated in **FIG. 8**. Any variations from the desirable alignment should be slow enough so as to avoid excessive rounding of the ultimate microlenses that would lead to low transmission efficiency. The analogy between the mechanical ruling and the laser writing starts to fail when neighboring concavities present a relative vertical offset, such as, the "piston" of the above-referenced, commonly assigned patent application entitled "Structured Screens for Controlled Spreading of Light." For some types of screen applications, the reduced efficiency might be acceptable. In other cases, the loss in focusing efficiency is intolerable.

[0066] As shown in **FIG. 9**, the requirement of alignment between the top of the concavities of the concave surface-relief structure is fully compatible with the requirement of some arrays that the focusing properties of the individual

microlenses vary randomly. In this case, the vertices of the concavities do not align, only their tops. A similar principle applies for two dimensional arrays.

[0067] After development, the surface-relief structure obtained with the laser exposure provides a first mold that can be used for replication. If the material that constitutes the photosensitive film is suitable for replication, than replicas of that master can be readily fabricated in convex form. If concave replicas are required, an intermediate replication step is necessary whereby a convex tool is formed, which is ready to produce concave arrays. Typically, the photosensitive film is not suitable for many replications and, as a result, molds are preferably made of, for example, stronger plastic resins.

[0068] A representative replication process is illustrated by the sequence shown in **FIG. 10A** through **FIG. 10C**.

[0069] **FIG. 10A** shows the initial surface-relief structure **101** in concave form with the tops aligned. The substrate, e.g., glass substrate, is identified by the reference number **102**. **FIG. 10B** shows another substrate **103** on which a plastic resin **104** has been deposited. This resin will be one more suitable than a photoresist for use or as an intermediate replication tool. **FIG. 10C** shows the result of replication of the intermediate replication tool of **FIG. 10B** to generate the desired array of convex microlenses **105**.

[0070] Sequences similar to that shown in **FIG. 10** can be used to make high efficiency, high fill factor arrays of concave microlenses with again the initial surface-relief structure being formed in a positive photoresist in concave form.

[0071] Although specific embodiments of the invention have been described and illustrated, it will be apparent to those skilled in the art that modifications and variations can be made without departing from the invention's spirit and scope. The following claims are thus intended to cover the specific embodiments set forth herein as well as such modifications, variations, and equivalents.

What is claimed is:

1. A method for producing a microlens array, said microlens array having a surface configuration having peaks and valleys and comprising a plurality of unit cells and a plurality of microlenses, one microlens per unit cell, said method comprising:

(a) providing a positive photoresist;

(b) exposing the positive photoresist with a laser beam having a finite beam width to form a master, said master having a surface configuration which is substantially the negative of the surface configuration of the microlens array; and

(c) using the master to:

(i) produce the microlens array, and/or

(ii) produce a further master used to form the microlens array, and/or

(iii) produce the first of a series of further masters used to form the microlens array;

wherein said microlens array comprises at least two convex microlenses at adjacent unit cells so that the master comprises at least two concavities at adjacent unit cells.

2. The method of claim 1 wherein said microlens array comprises only convex microlenses so that the master comprises only concavities.

3. The method of claim 2 wherein the master lies between a first plane and a second plane, the concavities extend into the master in the direction from the first plane towards the second plane, and the maximum sag of each concavity is at the first plane.

4. The method of claim 2 wherein the master lies between a first plane and a second plane, the concavities extend into the master in the direction from the first plane towards the second plane, and the location of the maximum sag of each concavity relative to the first plane varies between at least some adjacent unit cells at a sufficiently slow rate so that the focusing efficiency of the microlens array is not reduced below **75** percent.

5. The method of claim 1 wherein the master lies between a first plane and a second plane, the at least two concavities extend into the master in the direction from the first plane towards the second plane, and the distances between the apexes of the at least two concavities and the first plane are different.

6. The method of claim 5 wherein said distances are randomly distributed.

7. The method of claim 1 wherein at least one of said at least two concavities is anamorphic.

8. The method of claim 1 wherein the microlens array has a focusing efficiency of at least 75 percent.

9. The method of claim 1 wherein the microlens array has a focusing efficiency of at least 85 percent.

10. The method of claim 1 wherein the microlens array has a focusing efficiency of at least 95 percent.

11. The method of claim 1 wherein the fill factor of the microlens array is at least 90 percent.

12. The method of claim 1 wherein the fill factor of the microlens array is at least 95 percent.

13. The method of claim 1 wherein the fill factor of the microlens array is substantially equal to 100 percent.

14. A microlens array comprising a plurality of unit cells and a plurality of microlenses, one microlens per unit cell, said array having a focusing efficiency of at least 75 percent.

15. The microlens array of claim 14 wherein the array has a focusing efficiency of at least 85 percent.

16. The microlens array of claim 14 wherein the array has a focusing efficiency of at least 95 percent.

17. The microlens array of claim 14 wherein the array has a fill factor of at least 90 percent.

18. The microlens array of claim 14 wherein the array has a fill factor of at least 95 percent.

19. The microlens array of claim 14 wherein the array has a fill factor substantially equal to 100 percent.

20. The microlens array of claim 14 wherein the microlenses are convex microlenses.

21. The microlens array of claim 14 wherein at least some of the microlenses are anamorphic.

22. The microlens array of claim 14 wherein at least two of the microlenses differ from one another randomly.

23. The microlens array of claim 14 wherein the unit cells are close packed.

* * * * *

APPENDIX C – RELATED PROCEEDINGS

(NONE)